

A Study of the dependence of an Off-axis Detector Performance on the strip width and track finding/fitting parameters

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Abstract

This memo describes the study of the dependence of the sensitivity of an off-axis detector as a function of the detector strip width and track finding and fitting parameters. The cuts are optimized for the purpose of the rejection of background from ν NC, ν_e CC and beam ν_e while keeping a high efficiency for the oscillation signal: $\nu_\mu \rightarrow \nu_e$.

1 The particle identification

The reconstruction of MC events was described in [1]. The description of the detector can be found in [2]. We used the MC samples of which zpla = 12.5cm, with density of $1.15 \text{ g} \cdot \text{cm}^{-3}$ and zair = 5cm, corresponding to mass length $L = 13.8 \text{ g} \cdot \text{cm}^{-2}$, i.e. 30% rad.len.[2] The strip width was set to be 5 cm. Our purpose was to reduce the NC background to a level below that of the intrinsic ν_e in the beam, while keeping the signal ν_e CC efficiency as high as possible. This was done in two steps: to do the particle identification in the reco_minos programs and then to make the stringent cuts on the ν_e candidates. We made loose criteria for electron in the first step in order to keep a high efficiency and cut off most of the background in the second step.

The analysis program was based on the one described in [1] with a number of modifications. The principal ones were:

- a) The code had the capability of finding up to 4 tracks, the order being based on Hough transform parameters corresponding to maximum number of hits. The hits associated with previously found tracks are subsequently removed for the purpose of finding additional tracks.

- b) An effort was made to find neutrino interaction vertex whose location was used subsequently in defining acceptance cuts.

The following variables were used in the particle identification:

frac_gap_x/y the mean number of hit strips per plane assigned to each track in the x and y views. The hits in the first plane of the track were excluded from the numerator in order to eliminate the contributions from other tracks near the vertex. The number of gaps (planes that do not have hits associated to the track) was excluded from the denominator in order to make the distribution more distinguishable for electron tracks and muon tracks.

nhit_x/y total number of hit strips in the x and y views.

frac_roadf_x/y the fraction of the event hits assigned to the electron candidate.

curv_x/y the curvature for each track. The parabolic fit for the ntr^{th} track in the x view is of the form:

$aax(ntr) \times z^2 + bbx(ntr) \times z + ccx(ntr)$ [1]. We defined the curvature for this track as $curv_x(ntr) = 10000 \times aax(ntr)$ (in cm^{-1}). The charged pion as well as neutral pion tracks will generally have higher curvature than muon tracks due to the scattering.

asymm_xy In the case of NC, the neutrino will pass through the detector without leaving any hits, the hadron-caused hits will be in one half plane preferable to the other. This variable will record such asymmetry.

igap_nrvrt_x/y the number of gaps in the first three planes from the vertex. We would expect zero value for electron and muon tracks but non-zero value for π^0 cases.

z_gap_x/y the distance (in cm) between the most likely neutrino interaction vertex and the first plane that has hits.

In reco_minos program, a track is defined to be an electron in the x view if it satisfies the criteria:

$frac_gap_x(i) > 1.3 .and. z_gap_x(i) < 60 .and. igap_nrvrt_x(i) = 0$

ielec_x is then set to be non-zero for this track.

The definition of a muon is:

$frac_gap_x(i) < 1.3 .and. z_gap_x(i) < 60 .and. igap_nrvrt_x(i) = 0$

imu_x is then set to be non-zero for this track.

The definition of a photon is:

$frac_gap_x(i) > 1.3 .and. z_gap_x(i) > 60 .or. igap_nrvrt_x(i) \neq 0$

We then make further cuts on the electron candidate events and eliminate most of the background. If an event satisfies any of the following criteria, it will fail the ν_e CC identification:

electron cuts - fail to identify an electron track in either x view or y view
 $i_{elec_x}=0$.or. $i_{elec_y}=0$

energy cuts - cut off high energy and low energy background (mainly beam ν_e events)
 $n_{hit_x}+n_{hit_y}<46$.or. $n_{hit_x}+n_{hit_y}>86$
 $itrlen_hitf_x/y<10$.or. $itrlen_hitf_x/y>35$
 $frac_roadf_x/y<0.65$

muon cuts - cut off apparent muon candidates. A track should be long enough together with small curvature to be called a muon candidate.

$$imu_x/y \neq 0 \text{ .and. } itrlen_hitm_x/y > 7 \text{ .and. } curvm_x/y < 1$$

neutral pion cuts - cut off pions (from NC or $\nu_m u$ CC events)
 $asymm_xy > 0.29$
 $abs(curvf_x) > 4.1$.or. $abs(curvf_y) > 4.1$

2 Results

The Figure of Merit (FOM) was defined in the same way as in [2]. The assumptions about total flux and detector were:

- 4.0×10^{20} protons on target per year
- a 5 year run
- a 50kt detector
- an 85% fiducial mass
- far detector is 735km far from Fermilab with a transverse distance 10km

The oscillation parameters:

$$\sin^2 2\theta_{\mu\tau} = 1.0, \Delta m^2 = 2.5 \times 10^{-3} eV^2, \theta_{23} = 45^\circ \text{ and } \sin^2 \theta_{13} = 0.1$$

The number of events, signal efficiency and background rejection for 5cm *strip_width* and 30% rad.len sampling frequency are:

	signal	numu_NC	numu_CC	Beam_nue
before cuts	642.835	6928.21	10010.2	469.115
after cuts	232.131	15.1516	2.70826	24.5331
efficiency or rejection	0.361	2.2e-3	2.7e-4	3.8e-2

FOM = 35.7 which is very close to the result in [2].

3 The sensitivity as a function of strip width

We want to study the dependence of the detector performance on the transverse granularity by changing the parameter *strip_width*. The results were based on the events generated at SLAC which have poorer statistics than those at Fermilab. Also there are some differences in the experimental assumptions and oscillation parameters.

The experimental assumptions:

- 4.0×10^{20} protons on target per year
- a 200 kt·year run
- the mass length L between detector planes was $25\text{cm} \times 0.75\text{ g} \cdot \text{cm}^{-3} = 18.8\text{ g} \cdot \text{cm}^{-2}$, which is a little higher than the value $13.8\text{ g} \cdot \text{cm}^{-2}$ used in [2].
- far detector is 735 km far from Fermilab with a transverse distance 9 km

The oscillation parameters:

$$\sin^2 2\theta_{\mu\tau} = 1.0, \Delta m^2 = 2.8 \times 10^{-3} eV^2, \theta_{23} = 45^\circ \text{ and } \sin^2 \theta_{13} = 0.1$$

The higher Δm^2 value and the shorter transverse distance will result in larger signals, which will account for the higher FOM below. Also for the Fermilab run discussed above half of the data set was used to set the cuts and the other half was used to get the unbiased FOM. If we don't do that, the FOM will be a little higher. That was just the case for the analysis based on SLAC data set so it might account for some of higher FOM.

	signal	numu_NC	numu_CC	Beam_nue	efficiency	FOM
before cuts	796	7990.0	9714.0	489.2		
<i>strip_width</i>						
2cm	307.0	25.0	7.30	28.9	38.6%	38.8
3cm	307.4	21.2	6.0	29.2	38.6%	40.2
4cm	285.9	21.2	4.86	28.9	35.9%	37.9
5cm	289.3	22.5	4.86	28.4	36.3%	38.1
6cm	284.6	23.7	4.86	23.2	35.8%	38.9
8cm	282.6	33.7	7.30	28.9	35.5%	33.4

The above results show that the performance of the detector remains constant when the *strip_width* increases up to 6 cm. So 5 cm should be good enough to optimize the detector performance and the cost. A required transverse granularity of the detector is related to the local particles density on one hand and to the Moliere radius on the

other hand. Hadron and electron showers develop over large volumes in a low density detectors, hence the requirements on the transverse granularity of the detector will be relatively modest.

4 The sensitivity as a function of track finding/fitting parameters

We want to study the optimization of some track finding/fitting parameters. In the Hough transform, linear fit and later parabolic fit, we use several tolerance parameters to control the width of the track road [1]. All hits within the tolerance will be associated to the track. It's interesting to see the dependence of our reconstruction performance on these parameters. In order to maintain consistency, the tolerance parameters for different fit stages were always kept the same. We used the SLAC events and set *strip-width* to be *5 cm*.

tolerance	signal	numu_NC	numu_CC	Beam_nue	efficiency	FOM
20cm	295.4	25.0	6.1	28.9	37.1%	37.6
15cm	289.3	22.5	4.9	28.4	36.3%	38.1
10cm	296.3	20.0	1.2	29.4	37.2%	40.8
8cm	300.2	20.0	1.2	28.1	37.7%	42.0
7cm	312.8	30.0	2.4	29.1	39.3%	40.3

Since we set *strip-width* to be *5 cm*, it will not make any sense if we set the tolerance parameters below *5 cm*. From Fig.1 we noticed that the tolerance parameters will affect the variable *frac_roadf_x/y* significantly. In the low tolerance value cases, the backgrounds tend to pile up more (than for true electron) at low value of *frac_roadf_x/y* which is reasonable since fewer hits are associated with the electron candidate track, which will lower the fraction. Therefore we can conclude that lower tolerance parameters will improve the reconstruction performance by easily cutting off more backgrounds.

Another way to improve things is to adopt tolerance increasing along the track. The idea is that when an electron shower occurs, the track configuration will get wider and wider. If we increase the tolerance as the plane number increases, we can associate most of hits from the shower to the electron track, which should improve our analysis. We defined the tolerance as:

$$toler_fit = toler_init + toler_sl \times (plane_z(i) - plane_z(track_beg))$$

and listed the results for different *toler_init* and *toler_sl* values below:

toler_init	toler_sl	signal	numu_NC	numu_CC	Beam_nue	efficiency	FOM
10cm	0.01	281.8	17.0	1.2	25.9	35.4%	41.6
10cm	0.02	281.0	18.0	1.2	26.7	35.3%	40.7
10cm	0.05	283.4	21.0	2.4	26.7	35.6%	39.4
8cm	0.01	297.6	18.0	1.2	27.9	37.4%	42.6

toler_sl = 0.01 corresponds to a $\sim 4\text{ cm}$ increase of tolerance for a typical electron track. We conclude that *toler_sl* = 8 cm and *toler_init* = 0.01 are the optimal parameters for the reconstruction with the current experimental setting ($L = 18.8\text{ g}\cdot\text{cm}^{-2}$, *strip_width* = 5 cm).

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References

- [1] L.Camilleri, A. Para. The Reconstruction of ν_μ and ν_e Monte Carlo events. Off-Axis-NOTE-SIM-11.
- [2] L.Camilleri, A. Para. A Study of an Off-axis Detector Performance as a Function of Sampling Frequency. Off-Axis-NOTE-SIM-12.

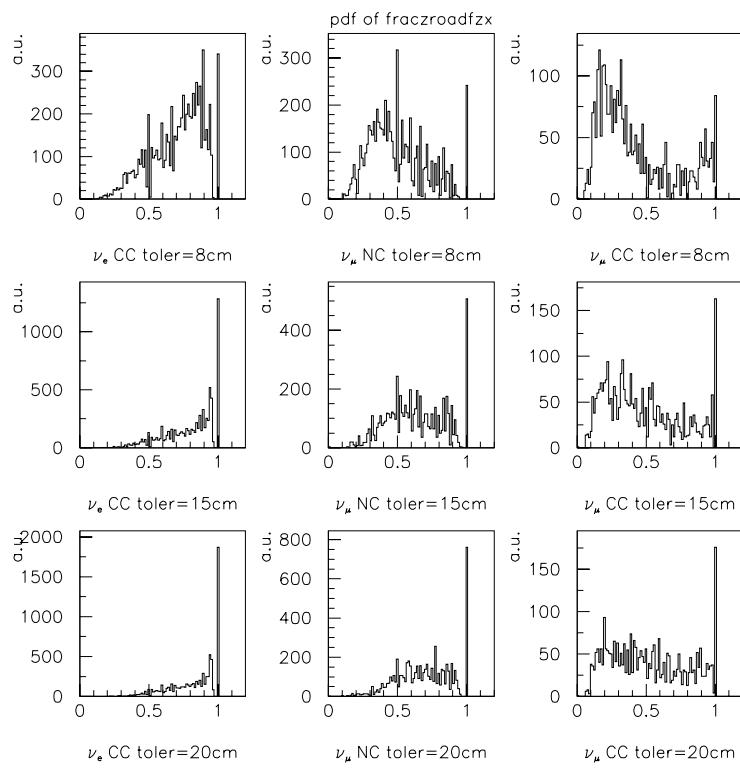


Figure 1: The distribution of $frac_roadf_x$ for different tolerance and beam components